Reprinted from
Israel Journal of Medical Sciences
Vol. 5, No. 4, pp. 926–930, July–August 1969
Printed in Israel

COMPUTER BASED MONITORING OF PATIENTS FOLLOWING CARDIAC SURGERY

RUSSELL M. NELSON, HOMER R. WARNER, REED E. GARDNER and J. D. MORTENSEN

Latter Day Saints Hospital, Salt Lake City, Utah, USA

The doctor has a new tool to help him with his job of collecting data, analyzing data, and making decisions about the care of patients. In medical terms, these activities are known as history taking, physical examination, diagnosis and treatment. This new tool is a general purpose digital computer and the Intermountain Regional Medical Program is designing new ways to make this available to practicing physicians. For the computer to serve in this role, it is necessary that convenient methods be developed for the physician or nurse to communicate with the machine. To accomplish this, a remote console has been developed which consists of a memory oscilloscope on which the computer can write messages and plot graphs and a 12-digit keyboard which the physician uses to send information to the computer. Also, a bank of solid state amplifiers is provided to allow the computer to read directly the signal coming from transducers such as pressure gauges, oximeters and electrocardiogram (ECG) leads. The electrical signals from these instruments are converted by an analogue digital converter to numbers between 0 and 1,000 at a maximum rate of 50,000 readings/sec. As many as 64 independent instruments may be sending information to the computer at any one time. Located at the central facility in the L.D.S. Hospital is a Control Data 3200 Computer and its auxiliary equipment. There is a card reader located in the hallway outside the computer room which can read 1,200 punch cards/min and is used to enter programs into the system. This is the 1,000 line/min printer which produces program listings and clinical reports of various kinds. Three types of media for storing information are available. Magnetic tapes are most economical but have the disadvantage that the information can only be written onto or read off the tapes sequentially, and it may take several minutes to find the desired data. Data may also be stored on magnetic disks. These are magnetic surfaces on which data is stored and accessed in a random fashion from designated locations. More versatile is the core memory. This machine can store 32,000 numbers in core memory and any number in this core memory can be accessed in 1.25 millionths of a second.

Now let us look at some of the ways the computer can help the physician in his task.

Clinical diagnosis. The physician sits at a remote console with the ECG and X-rays of the patient. He calls the program by dialing its code into a four-digit octal switch on the console and pressing an interrupt button. A series of multiple choice questions are then presented to him on the face of the oscilloscope. For those symptoms and findings present in his patient, he presses the corresponding number on the keyboard. Pressing 0 causes the next stage of symptoms to be presented. After entering the data in this fashion, the computer uses an equation of conditional probability based on a matrix of information gathered from previous patients. This matrix contains the probability of each symptom occurring in each disease and is used to calculate the probability that this particular patient has any one of 35 possible congenital heart diseases. After entering the last symptom, the code numbers of the symptoms entered are presented for confirmation along with the list of diseases whose probability is greater than 1%. In this case, the diagnosis is atrial septal defect with the probability of 81%. The print out at the central printer facility of the diagnosis is obtained for the record.

Clinical chemistry. Application of automated methods in clinical chemistry demands automated methods of data handling. In this 12-channel auto-analyzer, a voltage is generated for each reading which can be calibrated in terms of concentration of the substance being analyzed. This voltage which drives the recorder is also sampled at its peak by the computer. One reading is obtained on each of the 12 channels each minute during a run. The computer reads an external clock to record the time of day with each sample. Thus, if any sample is missed because the computer is down for more than a minute, this is apparent because of the time lapse encountered in the recorded data and the operator can enter the missing data through the keyboard at the remote station. Techniques are being devised for recognizing abnormal patterns among the results even when no single result is outside its expected limit.

Computerized ECG. Other forms of data collection require the presence of the patient. A set of seven electrocardiographic leads are connected to the patient in his room. These are evolved into three orthogonal leads giving a three dimensional representation of electrical forces generated by the heart. Using the three-channel data set which can be connected into a phone jack used by the patient's own telephone, the remote station is connected to the computer by dialing the appropriate number. Information is sent back to the patient's room from the computer by focusing a television camera on the face of the memory oscilloscope similar to those just seen. This can be visualized in any room of the hospital by dialing channel 6 on the television set. Messages are displayed on the television screen to instruct the technician on each step in the procedure and to display results. Discriminate functions have been derived which allow classification of each ECG into one of 20 categories, an assignment of the probability that this classification is correct. Parameters derived for each patient's ECG are stored in the computer to permit comparison of serial measurements on the same patient. A printed report is generated at the central facility.

Pulmonary functions. Another type of physiological measurement which has been automated is the determination of the mechanics of breathing in a patient. The patient's vital statistics are first entered into the computer by the technician: his sex, weight, height and age. These are then presented by the computer for confirmation. The patient then breathes into a spirometer whose displacement is measured by a potentiometer which moves as the spirometer moves. This voltage is sent to the computer and converted to numbers. Following a maximum inspiration, the subject exhales as hard and as fast as he can. From this signal, the computer calculates the forced vital capacity, the 1-sec volume, the maximum expiratory flow rate and the mid-expiratory flow rate and displays these numbers back on the oscilloscope along with the number which represents the percent of the predicted value for each of the variables based on height, weight, age and sex. The test is done at least twice. Maximum breathing capacity is then performed in a similar way. The whole test requires less than 5 min, including the entry of calibration data, barometric pressure and temperature.

Catheterization laboratory. Strip charts are no longer used in the catheterization laboratory. Instead, signals from strain gauges, oximeters and ECG are sent directly through the aid of the converter to the computer upon demand from the physician. A four-digit octal switch sends a code with each reading to signify the type of data to be processed, the state of the patient, and the position of the catheter tip in the circulation. When the code is sent, the interpretation of the code by the computer is written on the oscilloscope. In this example, the computer will sample the pressure wave 100 times/sec for 6 sec. The wave form is then averaged relative to the QRS complex. Three measurements are displayed. The peak systolic, the beginning diastolic, and the end diastolic pressure, along with the average wave form. The data can then be discarded or saved as part of the report on that patient. Oxygen saturation readings of the blood sample withdrawn through a cuvette oximeter are accomplished by sampling directly the output of the red and infrared cell of the instrument four times/sec until a stable reading is obtained. Logarithmic conversion in the computer permits values to be read back on the scope as percent saturation of the blood with oxygen. This same instrument is used for measuring cardiac output by the indicator dilution method. Dye injected into the circulation is detected by sampling continuously from a downstream sampling site. The curve is displayed on the oscilloscope as the measurements progress. At the end of the sampling, exponential extrapolation is carried out and superimposed over the original curve. Cardiac output and other parameters calculated from this dye curve are displayed to the operator. At any time during the procedure, and at the completion, the operator may review all the data collected, edit this data and ask for a print out of the report, along with the summary of the abnormal findings. The prime advantage of this on-line data collection approach is the fact that the analysis is complete while the catheter is still in the heart so that additional measurements can be made if uncertainties exist about interpretation. When the physician leaves the laboratory, the report is complete, including a report of abnormal findings made by comparison of all data with normal standards by the program.

Postsurgical monitoring. After surgery, the patient is taken to a special laboratory where a technician introduces a central arterial catheter. Using a special arm board to manipulate the patient's arm and extend his wrist, a thin wall 18-gauge needle is introduced percutaneously into the radial artery while monitoring the pressure on an oscilloscope. When the needle is in the artery, the rigid casing around the tiny catheter is withdrawn causing the catheter to be automatically advanced up the artery until its tip lies in the subclavian. No fluoroscopic control is needed since the catheter will not advance beyond this point to the angulation of the artery. Control measurements are then performed using a pressure pulse method to measure scope volume beat by beat. This method is calibrated once in each patient against the cardiac output measured by the dye method. In all, then measurements are made with each heart beat. These include stroke volume, heart rate, cardiac output and others. The needle is then removed. The catheter is dead-ended and taped to the patient's arm and he is returned to his room.

Measurements are made during surgery, and after surgery the patient is brought to a six bed intensive care ward. The venous and arterial strain gauges and an ECG lead are connected to the computer through plugs at the head of each bed. After calibrating the strain gauges, baseline measurements are made over 64 heart beats to determine the mean and SE of the mean for each variable. This initiates a schedule of measurements on this patient which will be made automatically at intervals determined by the program. As each schedule measurement begins, a green light is turned on. If any measurement differs from its mean by more than 3 SE, a red light is turned on. If one or more variables differ by more than 1 SE in the same direction on three successive measurements, a trend is established and a yellow light is turned on. To respond to these lights, the nurse or doctor presses a light which is also a switch interrupting the computer and causing a message to be displayed which identifies the variable out of tolerance, its last value and its baseline value.

The nurse may now take one of several courses. If she wishes to enter clinical information into the patient's record to explain the physiologic deviation, she presses option 1. She may choose to review the data already accumulated on this patient to get a better idea as to what the course of all variables has been over the last time interval. On pressing this option, she will see the baseline value displayed in the right hand column, along with the time that the baseline was measured, and in the left hand column, the variables measured at a subsequent point in time. Another option allows her to display the average central arterial pressure wave form obtained at the time of the baseline measurement and superimposed on this the average pressure wave form obtained at the time of the last measurement. Often, this will give a useful clue as to the cause of the physiologic disturbance. If the change represents an improvement in the patient, she may choose option 4 which will cause measurements to be made over the next 64 heart beats and a new baseline to be established on this patient. Prior to the end of each shift, a report is generated showing the values for each physiologic measurement at half-hour intervals along with the critical clinical data which was entered by the nurse.

This program is designed to train doctors and nurses in making decisions in a coronary care unit. The computer clocks an ECG across the face of the oscilloscope. Spontaneously, the pattern will change to represent a particular arrhythmia. The student must then make a decision regarding treatment of that condition. Since the response to treatment depends upon the nature of the arrythmia, the state of the circulation, and whether the patient is already on digitalis, options are provided for the student to obtain this additional information. When she presses option 3, five items are displayed for her choice. Item 2 causes the blood pressure to be displayed. Having recognized the rhythm and knowing the patient's blood pressure, she chooses to give a medication and a list of medications is displayed. When the operator chooses one of these medications, the computer, knowing the present state of the patient, references a transition table which contains the probability that the chosen treatment will change the patient's state to one of a series of other states. The random choice is made based on these probabilities. An ECG changes to reflect the new state resulting from this action. This provides the student with an awareness that the same treatment on one patient with a given condition does not necessarily produce the same result as that treatment on another patient in what appears to be the same state. The transition matrix can be updated periodically to reflect new information gathered on a given form of treatment from actual patients on the coronary care ward.

On command, or at the end of ten decisions, a chart is presented showing the course of the patient, the actions taken, and the best action at each point calculated on the basis of the probability that that action would return the patient to a normal sinus rhythm and a normal blood pressure. It should be emphasized that these activities may all go on simultaneously in the computer because of the time sharing system called Medlab which allows the computer to switch back and forth among the programs in memory to service each as the demand requires. Furthermore, these remote stations are located in five different hospitals; enough to service a whole community.